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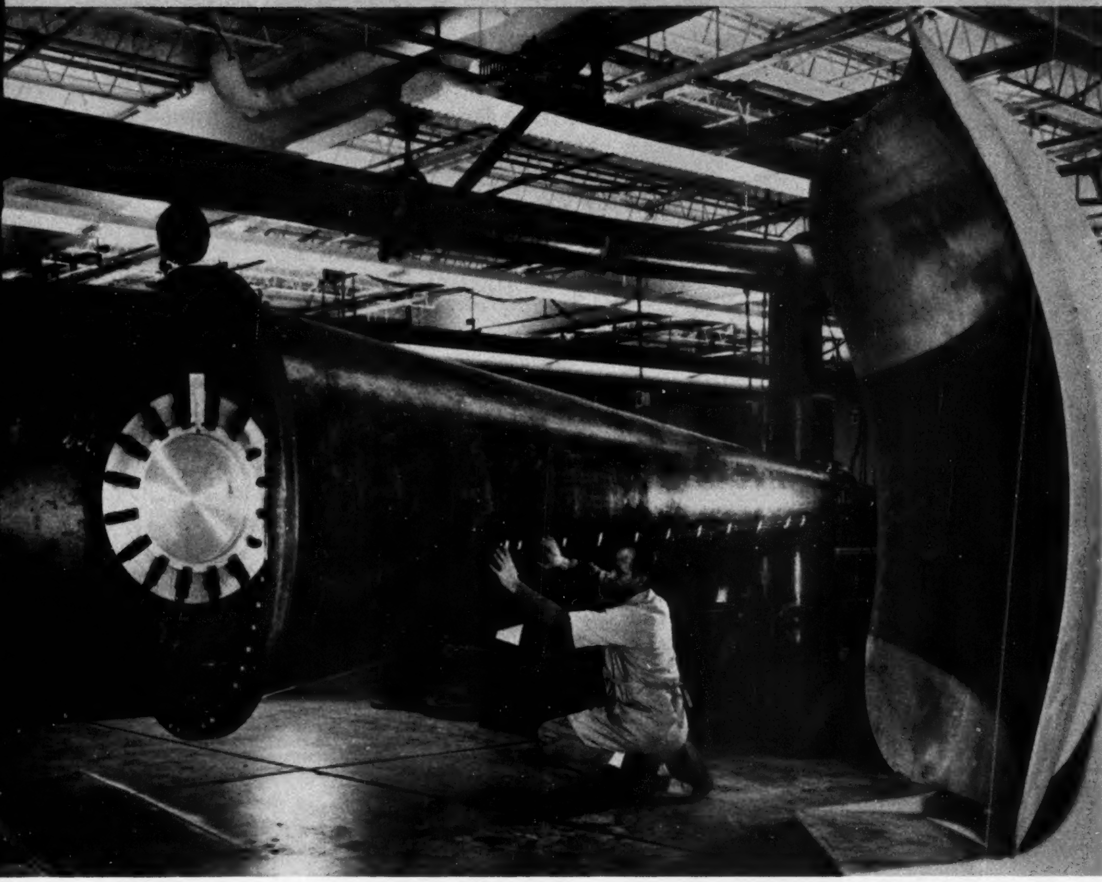


Fiberglass cone of CAL's new 6-foot hypersonic shock tunnel which permits the investigation of the interaction of microwave radiation with the plasma sheath about a hypersonic vehicle.

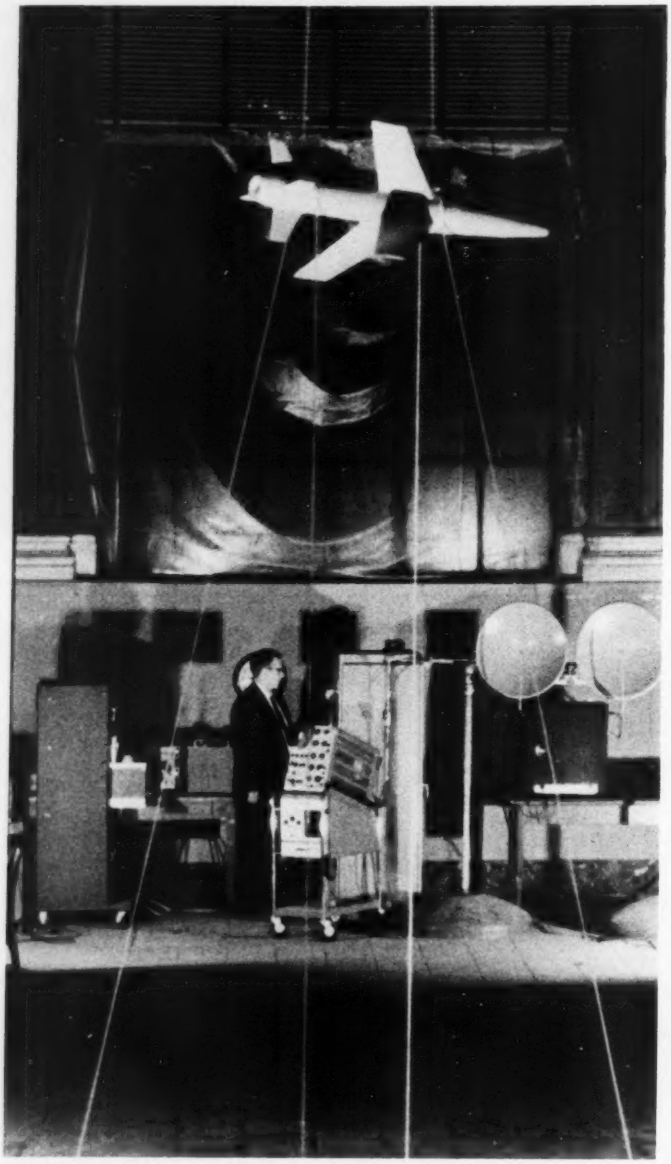
Radar Cross Sections and Defense Against Missiles . . .

by DR. SEVILLE CHAPMAN and DR. GORDON GRAHAM

Intercontinental ballistic missiles and submarine-launched ballistic missiles constitute the principal military threat to the continental United States. At present we have no defense against either, except the threat of retaliation. For manned bombers and cruise missiles, we have interceptor aircraft and anti-aircraft missile systems such as Nike Hercules.

In 1954 Cornell Aeronautical Laboratory, under Army sponsorship, began studies of defense against ballistic missiles. A distinction should be drawn between cruise missiles and ballistic missiles. Cruise missiles fly through the atmosphere like pilotless aircraft, usually at what would be called very fast aircraft speeds. On the other hand, ballistic missiles, once fired, follow a trajectory determined only by gravity and, if long-range missiles, follow a path which is mostly outside the atmosphere. Their speed is very great. In fact, in the year 1619 Kepler worked out the characteristics of orbits of celestial bodies which show that a typical arrival speed of a long-range ballistic missile is about 4 or 5 miles per second. Its flight time over a

*This article has been approved for publication by the Office of Security Review, but such approval does not necessarily imply endorsement by the Department of Defense of the opinions expressed herein.



Indoor Ka-band pulse range. Three radar cross section ranges, of Ka-cw and an X-band cw, in addition to the range shown above, are used by the Laboratory to study radar characteristics of targets. Cross section measurement precision possible with these ranges is about one db with sensitivity from 0.01 to 0.001 square wavelength.

5500-mile range is about half an hour. Short-range missiles from submarines may have speeds as slow as 2 miles per second, but their flight time, depending on range, may be only a minute. A quick reaction time is, for this reason, essential for a defense system.

The Nature of the Threat

One of the first tasks in the design of an anti-missile system is to define the nature of the threat: that is, what does the target "look" like to the device you plan to use in its detection? It is natural to think of radar for detecting objects, and so one asks what does a missile nose cone (the piece that contains the bomb) look like to a radar — how easy is it for the radar to "see" the target? The quantity that defines this radar visibility is called radar echoing area, or radar cross section. For a sphere of radius r, large compared to a wavelength, the cross section is πr^2, but in general a large radar cross section does not necessarily represent a large physical size.

Propeller-driven aircraft normally have cross sections of 10 to 100 or more square meters, jet aircraft from 1 to 10 square meters. Early missiles like the German V-2, which are something like small aircraft without wings, have cross sections even smaller than one square meter. A figure of two-tenths square meter has been quoted in the press as the design figure for an anti-ballistic missile system (see *Aviation Week*, March 24, 1958).

It must be apparent that the detection of missiles by radar is much more difficult than the detection of aircraft, since the radar visibility (or cross section) of missiles is several orders of magnitude less.*

Since missiles are difficult to see with radar, the radar must be high-powered, but the question is how high-powered!** Early studies by Cornell Aeronautical Laboratory, therefore, were directed toward determining not only the cross section of missiles at that time, but also what value the cross section might have if it were made as hard to detect as possible. More exactly, what shape would one choose for a nose cone to make it difficult for the radar of a defensive system to see it?

Standard textbooks reveal that the radar cross section of a mathematical cone seen nose-on is very small, about one millionth of a square meter! Thus, if this formula for a cone were applicable to missile nose cones, then the power of radars would have to be increased about a million times over the big radars used for detecting aircraft.

Now a missile nose cone, of course, is not a mathematical cone — the later extends to infinity whereas the former is only a dozen feet long (and may not even be conical).

Consequently, the Laboratory decided to measure the cross sections for possible shapes of missile nose cones. This theoretical and experimental program which began to yield data in 1955 is continuing. Every radar engineer knows that an ordinary shape such as a sphere can be distorted to the shape of a corner reflector by making a corner-shaped dimple in it, so that its radar-echoing area is increased a few orders of magnitude without significantly changing its true size. It is then plausible that there must be some way of distorting the sphere to decrease

*Cross section is a function of the angle at which the missile is pointed relative to the radar, the frequency of the radar, the polarization of the radar, and other factors, so that the radar cross section of a missile is not one number but a book of numbers. Most of the numbers of interest will fall within a factor of ten of some mid-range value.

**There are other means of detection besides radar, having advantages and disadvantages. . . . We do not exclude radars in aircraft, or satellites. . . .

its cross section. In fact, it is well-known that if a sphere is distorted into a long prolate spheroid (a cigar shape) its cross section nose-on can be reduced to as small a value as one wishes by making the spheroid long enough.

Let us suppose that the cross section can be reduced to a value intermediate between the 1945 missile value and the value of a mathematical cone. For illustration assume the cross section can be made just one-sixteenth as large. There is no implication here that, as a practical matter, the cross section can be reduced as much as a factor of 16, or conversely that it cannot be reduced as much as a factor of 1000.

Consequences of Reduced Cross-Sections

Now let us examine the consequences that would result if one reduced the cross section by a factor of 16. Other things being equal, the radar equation shows that the range of a given radar is reduced to half what it was (the fourth root of sixteen). It follows, then, that the time for the defensive missile system to react is also reduced to half. Suppose you had intended to detect at 400 miles, you would than detect at 200 miles! Is this serious? It turns out to be catastrophic!

An ICBM is approaching at about 4 miles per second, and you have allotted 400 divided by 4 or 100 seconds for your system to react. You must first detect, then track long enough to determine whether the ICBM will come within range of your defensive missile. Once in range, a few seconds still are required to ready and launch the defending missile, which may have been sitting on the launcher more or less ready to go for the past year. Had it been kept in complete readiness, it would have worn out in a few minutes, so there are some last-minute changes to make, such as speeding up the gyros.

If the defensive missile is to protect a significant area, it must be able to cover a significant distance after launching in its own time of flight. Suppose it travels one mile per second, then it can cover sixty miles in a minute — a distance perhaps suitable for defense of a large metropolitan area. Finally, one hopes to intercept the incoming missile while it is still far enough away (say 20 miles) so that even if it does go off, it will not do too much damage. When you add up all the times involved, you find that you use up all the 100 seconds (and that, of course, is the reason you had to plan to detect the missile 100 seconds before detonation). Cut that time in half and your defending missile hardly has had time to leave the launcher, and hence can defend only a negligible area.

Consequently, if radar cross section is reduced 16 times in order to maintain the originally desired detection range of 400 miles, a corresponding 16-fold increase of radar power is required. That is a tremendous increase of power for radars already about as powerful as we know how to make them.

In pushing toward invisibility of the target by reduction of cross section, other design factors such as payload, the thermal problem, the structural problem, and the aeroballistic problem must also be considered. In other words, the nose cone has to carry the warhead (or bomb), it has to be strong enough to survive re-entry, and it has to be able to withstand, without melting, the heating due to high-speed friction with the atmosphere upon re-entry. It also has to have the right shape and mass distribution to be aerodynamically stable, and not turn or slow down too much during the last phases of flight through the atmosphere, lest it miss the target.

Decoys Complicate the Problem

The decoy is a well known offensive technique for making things harder for the defense, to which any football quarterback can attest. In the case of missiles, this means that a bomb weighing perhaps a ton is the main part of the payload, but in addition, some other objects are thrown out to act as decoys. More specifically they can be considered as "penetration aids", or passive countermeasures to the possible defense system. By confusing or saturating the defense system, they help the nose cone to penetrate the defense and reach the target.

A good decoy is one which, to the radar, looks like another nose cone but which actually weighs very little. For example, in outer space metalized balloons having the shape of nose cones can make good decoys. Such balloons, however, immediately burn up and disappear as meteors do on re-entering the atmosphere at an altitude of about 300,000 feet. Thus, they may not provide too serious a problem to the defending system. Nevertheless, from 300,000 feet, the time to impact for a missile is uncomfortably short.

In the atmosphere, the decoys must have a radar cross section about equal to that of a nose cone and aerodynamic characteristics such that they will travel at about the same speed as the nose cone.

If the cross section of the nose cone is large, then the cross section of the decoy should be large. And, if the cross section of the decoy is to be large, the decoy ordinarily must itself be of fairly large size, which will give it a relatively high drag. If it is not to slow down too much, it must therefore be fairly heavy. Since there is a fixed payload in the offensive missile, there won't be room for very many of the heavy decoys. For example, a good decoy matching an obsolete 1945-style missile might have to weigh — to name a figure — a few hundred pounds. On the other hand, if the nose cone cross section is small, then the decoy cross section can also be small and, irrespective of how big the decoy had to be before, it must be clear that it can be a lot smaller than it was.

The important point is that the decoy weight (using our earlier example of cross section reduction by a factor of 16) might drop from 200 pounds to 10 or 20.

Consequently, the number of decoys that a missile could carry is increased by a very large factor and whereas a large cross section missile might be capable of carrying only a few decoys that would be effective, a small cross section missile might be able to carry many decoys because the decoys themselves could be quite small.

Thus, instead of having to deal with one entering nose cone, the anti-missile designer really has to consider how, from a cloud of many decoys suitably spread

BASIC RADAR EQUATION

$$P_R = \frac{G^2 \lambda^2 P_T \sigma}{(4\pi)^3 R^4}$$

where:

P_R = POWER RECEIVED FROM THE TARGET

P_T = TRANSMITTED POWER

G = ANTENNA GAIN = $4\pi A^2/\lambda^2$

A = EFFECTIVE AREA OF THE ANTENNA

λ = RADAR WAVELENGTH

σ = RADAR CROSS SECTION (ECHO AREA) OF THE TARGET

R = RANGE FROM ANTENNA TO TARGET

From the radar equation, for a given minimum detectable signal (least useful P_R) the tradeoffs among P_T, R and σ (G and λ fixed) can be seen readily.

out,* all of which look like a plausible nose cone to the radar, this system can select the one with the bomb in the few seconds that remain before the bomb will go off and terminate the engagement. The concept of shooting one missile at each of numerous decoys is prohibitive both in numbers and expense. Even though a defending missile costs many times less than an offensive missile, if there are many times more decoys than there are nose cones to be shot at, there is an economic balance. Even if the missiles are never shot, a side could lose the economic war simply by planning to shoot a defensive missile against every decoy, and by buying enough missiles to make it possible.

At this stage of the discussion it becomes clear that there are three major technological problems facing us relative to missile defense.

1. If the radar visibility of nose cones is substantially reduced, the power of the defending radars must be correspondingly (substantially) increased.
2. If the radar visibility is substantially reduced, then small (hence lightweight) decoys can be made. If they are lightweight, they can be numerous. (In any case, the U.S.S.R. is known to have missiles capable of carrying a large payload and hence, presumably many decoys). Numerous decoys pose a real discrimination problem.
3. The final stages of discrimination occur, of course, within the atmosphere. The substantial heat and light generated as bodies re-enter (and often burn up) creates much ionization. An ionized sheath around a nose cone or decoy could increase or decrease its cross section depending on circumstances. Thus, in addition to the general problem of decoy discrimination, one must study the effects of the atmosphere — as it affects radar characteristics, aerodynamic characteristics, infrared and visible light radiation characteristics.

*A swarm should be spread out enough so that only a small part of it would be knocked out by a single defending missile, and yet it should be compact enough so that the many objects in the swarm will be as confusing as possible and make for difficulty in discrimination.

Problems Not Insuperable

These three problems are difficult but it must not be assumed that their solutions are beyond us. For example, in 1957 (according to official U.S. Army press releases) Cornell Aeronautical Laboratory succeeded in radiating 21 megawatt peak power radar pulses at S-band, several times more powerful than had generally been thought possible. Cornell Aeronautical Laboratory now has in operation a 50-megawatt peak power, 50-kilowatt average power transmitter for use in studying the radar properties of the upper atmosphere, and for studying the problems of hyperpower. It has thus become apparent that radar power can be greatly increased over what was formerly thought to be a natural limit.

Likewise, the decoy problem was once thought to be insuperable: "It is obvious you can't discriminate against several dozen decoys." Remarkably enough, it turns out that this superficially obvious truth is just not so, or at least it is not so regarding some decoy types that have been studied (for example, see the Ballistic Missile Defense issue of Astronautics, October 1960). One can say only that the problems are difficult, some conclusions have been reached, useful results are at hand, much remains to be done, progress is being made. Solutions obviously will be costly, but appear not to be excessive.

Finally, consider the problem of the interaction of radar waves with the hypersonic shock environment about a missile nose cone moving four miles per second in the upper atmosphere. Solution is a particularly difficult task because it involves a very high order of skill in two (until now) unrelated experimental sciences, hypersonic aerodynamics and radar physics and also the use of unusual and complicated experimental apparatus.

Cornell Aeronautical Laboratory's leading position in hypersonic research is well known (for example, see Research Trends Volume 7, No. 2 and Volume 7, No. 4). We have just mentioned one of the many examples of radar research at CAL. These projects are under way, and results should begin to appear about the time you read this.

Research also is under way at other organizations on these problems. The problems are difficult and obscure.

Defense of soft targets like cities against sophisticated ballistic missile attacks will be the most difficult to provide. Nevertheless, if we achieve only a good order of partial success, we increase the probability of inhibiting our subjugation by blackmail; we increase the cost to the enemy of mounting an attack against us; we increase the probability of still having operational retaliatory capability if he does attack. All things taken together may tip the balance between war and no war. If we achieve the latter, then our success will have been total.

Of Men and Machines...

Human Factors Engineering

by DR. WILLIAM J. WHITE

Predicting the performance of machines is one of the many aspects of the science of engineering. Tools, machines and systems in order to be safe, reliable servants must be consistent with man's own characteristics, capabilities and preferences.

In the broadest sense almost every designer, engineer or project officer must endeavor to achieve the best match between man and his equipment. Today, with the emphasis on speed and maneuverability, scientists in all the physical disciplines, physics, physiology, psychology, mathematics and engineering, are developing specialists in the field of human factors engineering.

Five years ago about 200 human factors specialists were employed by the missile-electronics industrial complex. These same industries today employ more than 800 people in their human factors operations and the growth rate is continuing. Of these, approximately one-third are engineers; one-third are psychologists; and the last third is comprised of mathematicians, physiologists, physicists and anthropologists.

In 1958 a Human Factors Section was organized at the Laboratory as a focal point for research on the optimal utilization of man as an element in systems. The members of this section also serve as consultants in applying human engineering principles to the study and design of equipment and systems.

Man and the Vehicle

In recent years considerable research has been devoted to the study of the engineering properties of the human operator. The feedback model of servomechanism theory has been the starting point for the development of a set of theoretical formulations regarding human control processes. This approach has been particularly appropriate in the design of powered control systems and in the evaluation of the handling qualities of many types of vehicles.

One direction this research has taken is to gather pilot opinion data as a means of defining the stability and control characteristics conducive to good aircraft handling qualities. Extensive flight tests performed in the Laboratory's variable stability aircraft resulted in the iso-opinion plots of pilot opinion data. These plots were obtained with various short period natural frequencies and damping ratios. It is apparent from Figure 1 that the natural frequency and damping associated with good handling qualities represent a second-order system with a response time of about one second.

Another approach to the matching of men with machines is based on the development of an understanding of the pilot as a unique servo unit in a complete servo control system. Characteristics of the human operator when functioning as a servo unit now can be described by a family of quasilinear transfer functions. Although a man adapts the form of his equalizing characteristics to achieve good low-frequency, closed-loop system response, it appears that variations are largely systematic and predictable. In a series of well-conceived and executed experiments, McRuer[1] and his associates have related pilot opinion data to the transfer function adopted by pilots in different control situations. Hall's[2] data, Figure 2, for example, show that there is a fairly broad gain region associated with acceptable and good pilot opinions.

The handling qualities concept is concerned with a description of the dynamic characteristics of a system when man is not present in the control loop. These characteristics are expressed by stating the time required to reach a steady-state condition after the application of a disturbance, the damping ratio, natural frequency and other factors. Good handling qualities are obtained when the dynamic characteristics are matched with those of the human controller so that good closed-loop performance is obtained. A pilot of World War I made the point more eloquently when he said of his airplane: "She is a bonny monoplane that responds to my hand like a tender-mouthed horse".

Although emphasis has been placed on aircraft handling qualities, man is in the control loop of many other vehicles. In Figure 3, the open loop characteristics of several vehicles are presented in qualitative form. Static stability is associated with the tendency of a system to restore itself. It is frequently referred to as

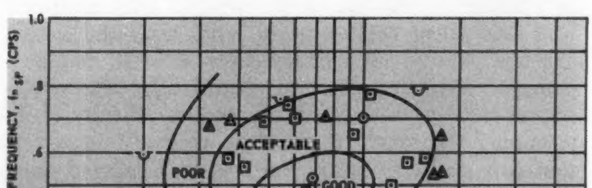


FIG. 1 — **Aircraft longitudinal handling qualities criteria as derived from pilot opinion data.**

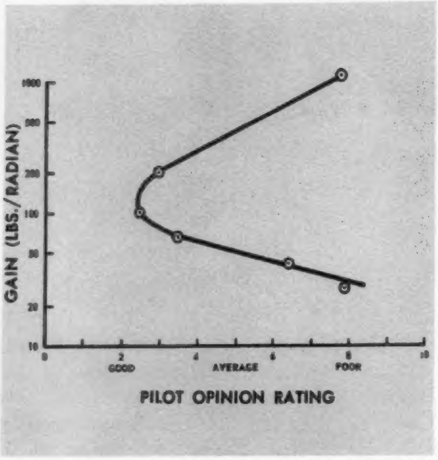
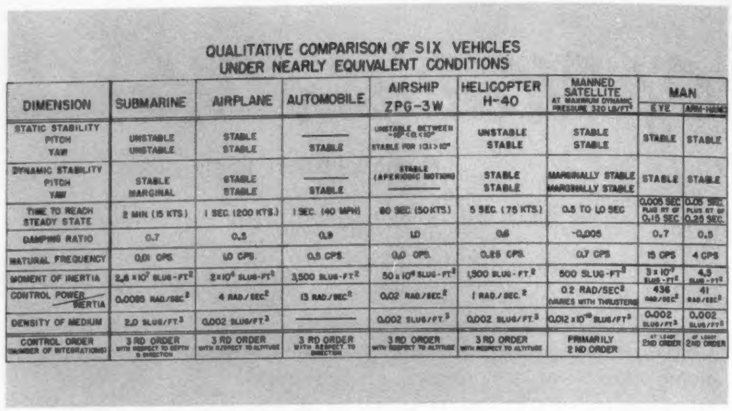


FIG. 2



QUALITATIVE COMPARISON OF SIX VEHICLES UNDER NEARLY EQUIVALENT CONDITIONS

DIMENSION	SUBMARINE	AIRPLANE	AUTOMOBILE	AIRSHIP ZPG-3W	HELICOPTER H-40	MANNED SATELLITE AT MAXIMUM DYNAMIC PRESSURE 320 LB/FT²	MAN	
							EYE	ARM-HAND
STATIC STABILITY PITCH YAW	UNSTABLE UNSTABLE	STABLE STABLE	—— STABLE	UNSTABLE BETWEEN $-10° < \alpha < 10°$ STABLE FOR $\lvert\alpha\rvert > 10°$	UNSTABLE STABLE	STABLE STABLE	STABLE	STABLE
DYNAMIC STABILITY PITCH YAW	STABLE MARGINAL	STABLE STABLE	—— STABLE	STABLE (APERIODIC MOTION) ——	STABLE STABLE	MARGINALLY STABLE MARGINALLY STABLE	STABLE	STABLE
TIME TO REACH STEADY STATE	2 MIN (15 KTS)	1 SEC. (200 KTS.)	1 SEC. (40 MPH)	60 SEC. (50 KTS.)	5 SEC. (75 KTS.)	0.5 TO 1.0 SEC	0.005 SEC PLUS RT OF 0.15 SEC	0.05 SEC PLUS RT OF 0.25 SEC
DAMPING RATIO	0.7	0.5	0.9	1.0	0.6	-0.005	0.7	0.5
NATURAL FREQUENCY	0.01 CPS	1.0 CPS.	0.5 CPS.	0.0 CPS.	0.25 CPS.	0.7 CPS	15 CPS	4 CPS
MOMENT OF INERTIA	2.6×10^7 SLUG-FT²	2×10^4 SLUG-FT²	3,500 SLUG-FT²	50×10^6 SLUG-FT²	1,500 SLUG-FT.²	500 SLUG-FT²	3×10^{-7} SLUG-FT²	4.5 SLUG-FT²
CONTROL POWER/INERTIA	0.0085 RAD./SEC.²	4 RAD./SEC.²	13 RAD./SEC.²	0.02 RAD./SEC.²	1 RAD./SEC.²	0.2 RAD/SEC² VARIES WITH THRUSTERS	436 RAD/SEC²	41 RAD/SEC²
DENSITY OF MEDIUM	2.0 SLUG/FT.³	0.002 SLUG/FT.³	——	0.002 SLUG/FT.³	0.002 SLUG/FT.³	0.012×10^{-10} SLUG/FT³	0.002 SLUG/FT³	0.002 SLUG/FT³
CONTROL ORDER (NUMBER OF INTEGRATIONS)	3 RD ORDER WITH RESPECT TO DEPTH & DIRECTION	3 RD ORDER WITH RESPECT TO ALTITUDE	3 RD ORDER WITH RESPECT TO DIRECTION	3 RD ORDER WITH RESPECT TO ALTITUDE	3 RD ORDER WITH RESPECT TO ALTITUDE	PRIMARILY 2 ND ORDER	AT LEAST 2ND ORDER	AT LEAST 2ND ORDER

FIG. 3

the spring or stiffness in the system, and is more accurately defined as the slope of the curve of restoring force or moment plotted against the amplitude of the disturbance from trim. The dynamic stability of a system is the real stability of motion. Here the concern is with the characteristics of the motion once a disturbance has been removed and the device must function independently. These disturbed motions can be defined quantitatively in several ways: time to steady state, damping ratio and natural frequency.

The remainder of the chart is concerned with the magnitude of the parameters which describe the vehicle motion and the control task of the operator. Control order or the number of integrations required of the operator in closing the control loop has been used as a means of assessing the difficulty of the operator's task. Although it is reasonable to conclude that the order of a control system greatly increases the complexity of the operator's task, this is a misleading simplification of the control problem. More significantly, it is the response time of the system that is important to the handling qualities problem.

The submarine, the airplane and the automobile each represents a different set of dynamics to the human controller. The response time of the automobile is an order of magnitude faster than that of the submarine. As a result, the motorist has no difficulty in determining the precise point in a turn at which recovery should be initiated to stabilize at the desired final condition. The submarine, because of its large mass and inertia, together with small hydrodynamic stiffness, results in extremely large lags between control input and vehicle response. Thus, the diving officer has difficulty in determining the depth at which a recovery should be started in order to produce a fast, well-damped depth change. Because the human is so adaptable, with practice and training he can modify this control situation and close the loop satisfactorily provided only slow or gradual maneuvers are attempted. Many vehicles controlled by man impose difficult and exacting tasks upon the human operator.

Man-Machine Coupling

Traditional man-machine control links have been restricted to movement of an arm or leg. Currently under investigation is the potential use of the eye and head as a means of coupling men to the machines they operate. Benefits that could be derived from such an approach include more rapid and accurate responses, freeing the limbs for other tasks, time sharing of several central tasks which must be performed simultaneously and possible savings in weight. The rather unique characteristic of the human eye can be seen in Figure 3. These data are based on the analysis of eye response to a 20 degree step displacement of light in the horizontal plans.

Various techniques for sensing eye movements have been investigated. A method which seems well adapted to many applications involves a set-up analogous to the light beam galvanometer wherein the eyeball corresponds to the movement, and the corneal surface represents the attached mirror. Specifically, a head-mounted optical system focuses a narrow beam of light on the cornea and records (or instantaneously senses), the direction of the reflected beam (e.g., by position on a photosensitive solid state device). The reflected beam direction is a measure of instantaneous eye position (the relation being linear over a considerable angular range). The advantages of this technique are its extreme sensitivity, freedom from null drift, constancy of calibration, and absence of any requirements for special preparation of the skin to accommodate electrodes as in the electro-oculogram method.

The mechanization of optical eye movement sensing has progressed in recent months, to a point where a complete sensing and recording unit weighs less than three pounds and can be mounted on a helmet. Such a unit (Page 5) is currently in use at Cornell Aeronautical Laboratory under an experimental program aimed at measuring (by photography) the visual behavior of pilots during flight.

In part as a result of the experimental work accomplished to date it is believed that direct tracking and control capabilities of the eye can be exploited usefully for many important tasks.

Non-Computational Uses of Computers

The stimuli to which humans respond in their everyday activities are so complex that some abstraction of them is often required in human factors research. By developing such abstractions, it is possible to learn more about how humans respond to natural sensory stimuli

and to develop the most effective artificial sensory stimuli for particular purposes.

The complexities involved in such research have led psychologists to turn to digital computers as instruments for the creation of both visual and auditory experimental stimuli. Visual stimuli are produced by photography from the CRT output available with many digital computers. Auditory stimuli are produced by attaching an amplifier and loud speaker to a relay or set of relays in a computer, an arrangement currently used for monitoring the machine's operations.

An example of a program for generting visual stimuli on a digital computer is one written by Dr. B. F. Green[3] at M.I.T.'s Lincoln Laboratory. In one of its several modes of operation, a set of points is selected in a three-dimensional area. Projections of the points on a fixed plane are computed and spots representing the points on the projection plane are produced on the CRT and photographed. The axes of the three-dimensional space are rotated in some manner and successive projections of the points are computed, plotted and photographed. The result is a motion picture of spots of light of constant size, shape and brightness, moving about on a plane, which give the appearance of spots moving in three-dimensional space. By such technology, it is possible to study the effects of various parameters in a mathematical model of space perception by producing the visual stimuli directly from mathematical formulas, varying such parameters as distance of the projection point, speed and axis of rotation, number of elements in the display, etc. The stimuli thus produced are used in experiments with human subjects, and formal relationships between the parameters of the stimuli and the human responses may be derived.

As a part of a research program using this method, pairs of stimuli were presented to two groups of subjects, asking one group to choose the stimulus in each pair which gave the stronger impression of occurring in space and the other group to choose the pattern which appeared more coherent.[4]

Computers can be used in analogous ways in studying many other aspects of visual and auditory perception. A great many methods of presenting two-dimensional representations of three spatial dimensions, for example, could be simulated by changing the values of parameters in a computer program, thus avoiding building special hardware, but still permitting human observation of all of the possibilities. Most important, however, is that by the use of high-speed digital computers, mathematical abstractions of the visual or auditory environment can be converted into real visual and auditory stimuli for experimental research.

The areas in which the human factors specialist applies his knowledge of the abilities and behavior of man are as diverse as engineering itself. At some point in every military or industrial system, whether in the continuous direction of the system or only in pressing a button to begin its automatic operation, there enters the human factor, and the optimization of this aspect of the system becomes the concern of the human factors engineer.

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Before joining the Laboratory in 1948, Dr. Chapman was an Assistant Professor of Physics at Stanford University. He also taught at the University of Kansas and at the University of California from which he received his B.A. and Ph.D. degrees.

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RECENT
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PUBLICATIONS

The Laboratory invites requests for its unclassified publications as a public service. Supplies of some publications are limited, and those marked with an asterisk may be distributed only within the United States. Please direct your request to the Editor, Research Trends, Cornell Aeronautical Laboratory, Buffalo 21, New York.

"PERCEPTUAL GENERALIZATION OVER TRANSFORMATION GROUPS," Rosenblatt, Frank; Reprinted from "Self-Organizing Systems", Pergamon Press; 100 pages.

This paper is concerned with the question of how a brain, or brainlike system, can recognize similarity among the various possible transformations of a sensory pattern, or image.

"SIMULTANEOUS VHF AURORAL BACKSCATTER MEASUREMENTS", Flood, Walter, A.; Reprinted from Journal of Geophysical Research, Vol. 65, No. 8; August 1960; 7 pages.

Simultaneous auroral echoes at 49.7, 143.5, and 226 Mc/s have been recorded using scaled radar equipments. Analysis indicates that the wavelength dependence of auroral echoes varies from λ 3.5 for frequencies of 49.7 and 143.5 Mc/s to λ 6.5 for frequencies of 143.5 and 226 Mc/s. These measurements are in reasonable agreement with Booker's theory of auroral echoes if the scale sizes (measured transverse to the magnetic field) are taken as roughly 40 cm. Evidence for nondeviative absorption at 50 Mc/s is also adduced.

"THE LANDING CAPACITY OF A RUNWAY", Blumstein, Alfred; Operations Research, V. 7, No. 6; pp. 752-763; November-December 1959; 11 pages.

The ANALYTICAL method described in this paper provides a means for determining the landing capacity or service rate of any single runway in IFR as a function of the mix of aircraft landing at the runway, the minimum landing separation, the length of the common glide path, and the minimum separation at the beginning of the common path (the gate).

"A GRAPHICAL SOLUTION FOR NORMAL SHOCK WAVES IN REAL GASES", Treanor, Charles E.; J. of the Aero/Space Sciences, V. 27, No. 2; pp. 158-160; February 1960; 2 pages.

The SOLUTION of the equations for conditions behind a normal shock in a real gas usually represents a tedious and time-consuming part of shock-tube research. In the present note, a rapid graphical method of obtaining such solutions is described. The accuracy is limited only by the accuracy of the graph available for the gas properties.

"A PRELIMINARY ANALYSIS OF THE KINETIC BEHAVIOR OF ROADS", Clark, Daniel, C.; CAL Report No. YM-1304-V-2; July 7, 1960.

This report summarizes the results of a preliminary analysis of the kinetic behavior of roads conducted for the Bureau of Public Roads, U. S. Dept. of Commerce. The work was performed to establish a preliminary mathematical model of road, which includes transient as well as steady-state responses of the road to various time varying road load forces.

"STRUCTURAL AND INSULATIVE CHARACTERISTICS OF ABLATING PLASTICS", Vassallo, Franklin A., Wahl, Norman E., Sterbutzel, Gerald, A., Beal, John, L.; Presented: WADD Conference on Behavior of Plastics in Advanced Flight Vehicle Environments; Feb. 16-17, 1960; 22 pages.

Results of ablation research conducted on reinforced plastic materials at moderately sever heating conditions are reported. The materials investigated include laminates of melamine, phenolic, and silicone resins reinforced with glass fabric as well as phenolic and silicone asbestos laminates. Experimental data are given for rate of material loss, effective heats of ablation, and depth of material degradation.

"THERMODYNAMICS AND HEAT FLOW ANALYSIS BY LAGRANGIAN METHODS", Biot, M. A.; CAL Report No. SA-987-S-8; July 1959; 26 pages.

New procedures for the analysis of heat flow are summarized and further applications are presented. This formulation is based on the introduction of a new thermodynamic potential, the concept of flow field as a state variable, and the use of Lagrangian techniques and generalized coordinates.

"THE SHOCK-LAYER CONCEPT AND THE THREE-DIMENSIONAL HYPERSONIC BOUNDARY LAYER", Cheng, Hsien K.; Presented: 40th Meeting of the Bumblebee Aerodynamics Panel at Silver Spring, Md.; May 12, 1959; 12 pages.

This paper describes briefly the shock-layer concept and its applications to certain three-dimensional hypersonic flows and associated problems of hypersonic laminar boundar layers.

"MOTIONS OF SKIDDING AUTOMOBILES", Radt, H. S., Jr. & Milliken, W. F., Jr.; Presentation at the SAE Summer Meeting, Chicago, Ill.; June 5-10, 1960; 22 pages.

This paper demonstrates that a simple analysis of the lateral skidding of an automobile is practical; that this mathematical model will predict a number of experimentally verifiable skidding characteristics and may be used for either simulation or calculation purposes. It should be emphasized, however, that the objective of the paper is more one of illustrating the possibilities of studying skidding in the form of an integrated analysis than the development of a model for detailed design use.

"INPUT-OUTPUT CROSS-CORRELATION FUNCTIONS FOR SOME MEMORY-TYPE NONLINEAR SYSTEMS WITH GAUSSIAN INPUTS," Leland, Harold R.; Reprinted from the Transactions of the AIEE Winter General Meeting, New York, N. Y., January 31 - February 5, 1960, Paper No. 60-115; 5 pages.

The inclusion of relay hysteresis in a second-order delay servo was found to result in the first maximum of the input-output cross-correlation curve being lowered and shifted in the direction of increased output delay. The necessary curves and a general method for studying the effects of relay hysteresis are presented.

"PERCEPTRON APPLICABILITY TO PHOTOINTERPRETATION," Murray, Albert; CAL Report No. VE-1446-G-1; November 1960; 57 pages.

This Phase I report describes experiments concerned with operations typical of or fundamental to those required in the interpretation of aerial photographs, and demonstrates the perceptron's ability to detect targets alone, in company with other similar objects, on cluttered backgrounds.